Faculty of Engineering and Information Technology

School of Civil and Environmental Engineering

Centre for Built Infrastructure Research

Investigation into the Ductile and Damping Behaviour of Concrete Incorporating Waste Tyre Rubber

By

Negin Sharifi

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CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Negin Sharifi

Negin Sharifi

March 2012

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ABSTRACT

Sustainable development has grown to be a major concern to the construction industry with the main effort and attention in recent times devoted to developing innovative solutions to preserve the environment and natural resources. One suggested approach in aiding the conservation of natural resources is to recycle waste material for innovative use in construction applications.

This thesis reports on the fundamental findings of an investigation into an elastomeric modified concrete (EMC), in particular its ductile and damping performance. This first-of-its-kind-in-Australia EMC incorporates Styrene Butadiene Rubber (SBR) waste tyre granules as a partial replacement of fine and coarse aggregates.

Another significant feature of this project is that until now 100% Portland cement plain concrete has been utilised to evaluate the mechanical performance of EMC reported in literature, however, in this study the use of a supplementary cementitious material, that of fly ash (FA), is suggested as a partial replacement of Portland cement to create a more environmentally friendly construction material. Moreover, in order to examine the improvement of adhesion properties between the SBR granules and the cementing matrix, a styrene butadiene (SB) copolymer emulsion has been introduced to the couple of mixes.

In the first experimental work stage two sets of EMC were prepared; one with small SBR granules (1 to 4 millimetres) in proportions of 5%, 10% and 15% of the total weight of aggregates; the other with larger SBR granules (12 to 15 millimetres) in proportions of 2%, 4%, 6% and 10% of the total weight of aggregates. In order to evaluate the damping and ductility properties of concrete, several tests were conducted following Australian Standards (AS) and American Society for Testing and Materials (ASTM), including compressive strength, static chord modulus of elasticity, modulus of rupture and dynamic modulus of elasticity.

Compared to the control concrete, EMCs demonstrated lower density (mass per unit volume) and higher air content with increasing additions of SBR granules to EMCs. Furthermore, the compressive strength was found to decrease with increasing additions of SBR granules to EMCs. In contrast, static chord modulus of elasticity (MOE) and

modulus of rupture (MOR) of EMCs were found to increase compared to the control concrete. Unlike the control concrete, EMCs did not exhibit a brittle-like failure.

In the second experimental work stage, five reinforced beams (two for four point bending and three for three point bending tests) were made based on Australian standards. There were two sets of tests conducted on beams: destructive and non-destructive. Four point bending and three point bending tests were used to investigate the static properties of beams. To evaluate dynamic properties, hammer test was carried out prior to initiation of loading and also after failure of beam in four point bending test. The stiffness and maximum load of the beams decreased with the addition of SBR granules, however, the damping ratio of the beams increased. The project also included simulation and modelling of static tests using analysis by computer programs.

This study encompassed a large experimental component and through specific testing, the best performing materials is selected to achieve the highest damping-to-ductility ratio.

NOTATION

A_s = area of the steel reinforcement

C = damping coefficient

c_{cr} = critical damping coefficient

d = the effective depth

Δ = deflection

ε = strain in concrete

E = modulus of elasticity

EI = flexural Stiffness

f = frequency

f_s = the ultimate strength for the steel reinforcement

f_c = the compressive strength of the concrete beam

f_{cm} = average value of modulus of elasticity

I = the moment of inertia

k = stiffness of the system

L_c = length of specimen, for calculation of concrete dynamic modulus of elasticity

L = the span length

M = mass of specimen for calculation of concrete dynamic modulus of elasticity

M_u = the maximum bending moment

m = mass of the system

m'= number of cycles for calculation of the damping of the beam

n = fundamental transverse frequency

n' = fundamental longitudinal frequency

P = the applied load

T = correction factor, for calculation of concrete dynamic modulus of elasticity

t, b = dimensions of cross section of prism, for calculation of concrete dynamic modulus of elasticity

u_n = displacement on the curve at nth cycle for calculation of the damping of the beam

u_{n+m} = displacement on the curve at (n+m)th cycle for calculation of the damping of the beam

ω = natural frequency of the undamped system

ω_n = natural frequency of the beam

ξ = damping Ratio

ρA = mass per unit length

LIST OF SYMBOLS

AC: Air Content

ACI: American Concrete Institute

AS: Australian Standards

ASTM: American Society for Testing and Materials

BSG: Bulk Specific Gravity

EMC: Elastomeric Modified Concrete

FA: Fly Ash

FRC: Fibre Reinforced concrete

HWR: High Range Water Reducing Admixture

LVDT: Linear variable differential transformer

MC: Moisture Content

MOE: Modulus of Elasticity

MOR: Modulus of Rupture

PC: Portland Cement

PP: Polypropylene

PVA: Polyvinyl-alcohol

SB: Styrene Butadiene

SBR: Styrene Butadiene Rubber

SCM: Supplementary Cementitious Material

SL: Shrinkage Limited

SSD: Saturated Surface Dry

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